National Aeronautics and Space Administration

Computing, Information and Communication Technologies Program
Information Technology Strategic Research Project
NeuroElectric Machine Control Sub-Project

NeuroElectric Machine Control Task
UPN 302-05
FY04 Plan

Agreements:

________________________________ ____________
Joseph J. Totah Date
Approve: Level III NeMC Sub-Project Manager

________________________________ ____________
Dr. Kevin R. Wheeler Date
Submit: Level IV NeMC Task Lead

1. Background

NeuroElectric Machine Control (NeMC) is a sub-project under the Information Technology Strategic Research (ITSR) Project. The objectives of NeMC are to improve integrated human/system performance, as well as reduce development time and operational cost. The approach in NeMC builds upon a system-level approach by developing outer-loop technologies to intelligently maneuver a vehicle under nominal and off-nominal conditions, developing machine learning algorithms to tighten the control loop, providing a new computer interfacing modality in immersed human machine systems, and exploring physics based approaches to estimation and prediction.

These technologies will have broad application to launch vehicles, space systems, and robotic devices. The intent is to leverage information technologies and core competencies in soft computing and computational intelligence to support NASA's Pillars and Goals. The value added to NASA's missions resulting from this investment will be to improve safety, reduce cost (during design/development and operation), increase efficiency, and extend operational life for flight critical components, subsystems, overall vehicle, and fully integrated human/machine systems.

2. Objective

The objective of this sub-project is to provide the capability of non-mechanical, bio-electric interfaces between humans and machines. The multi-modal nature of this work will:

- Develop new modes of interaction that operate in parallel with existing modes such as typing and walking.
- Augment human-system interaction in wearable, immersive and data rich environments by increasing bandwidth and quickening the interface.
- Develop silent speech recognition technology using EMG data signals.
- Develop EMG based gesture interfaces.
- Develop EEG technology for brain computer interfaces and adaptive automation.

3. Technical Approach

The approach is to validate the concepts of silent speech recognition, gesture-based device control, brain computer interfaces (BCIs) and state-assessment for adaptive interfaces in a series of increasingly ambitious demonstrations. For silent speech this will begin with simple individual words and progress to connected and continuous speech. Current contact based wet and dry electrode sensors may prove insufficient for this task due to limitations in signal richness, problems in surface measurement, and contact maintenance. An alternative sensor development in part funded by this project is a non-contact free space electric potential sensor which promise a number of advantages in signal clarity, resistance to displacement, and sensitivity. We propose conducting a set of experiments for both EMG and EEG. Initially, we would use wet electrodes and progress to non-contact capacitive electrodes. These signals would feed advanced pattern recognition technologies to process, recognize, and utilize the subvocal speech, gestures, and BCI in a controlled environment.

Demonstration of Pattern Recognition of EMG Based Words
The initial study of silent speech involves placing wet EMG electrodes on the throat of the participant. This requires the careful selection of the locations for optimal signal measurement. Once the optimal locations have been determined, we then will need to concentrate on how the data will be transformed into a representational feature space suitable for a pattern recognizer. This will involve using discrete wavelet transforms both to determine an optimal basis and for noise reduction. The resulting signal spectral densities can then be used as one feature space. The training methodology of the pattern recognition algorithms will then be developed and evaluated.

The on-line patter recognizer developed previously will be integrated into a graphical display environment to depict a useful task that could be accomplished with this technology. The generalizability of this system across multiple days will be evaluated and extended to cope with the differences found across individual users.

Integrate Biosignal Pattern Recognition System with Capacitive Sensors
The signals from wet electrodes will be different from those measured by non-contact capacitive electrodes. These new electrodes are currently under development and if successful will represent a breakthrough in bioelectric sensing technology. Since these electrodes do not require a direct connection with the skin as required by wet electrodes, they do not suffer from the same disadvantages such as inconsistent impedance during long duration use. The pattern recognition software will have to be modified to make use of these new signals following our wet electrode work. The transition from wet to capacitive electrodes is necessary because the new electrodes will not be ready in time for the start of this work. Once the comparison has been made, then the recognition software will be re-trained on the new data and a performance evaluation will be performed.

EEG Control in the Presence of Motion
In order to be able to use EEG for control in a realistic setting, it must be shown to work when a participant is moving about, which could include such common tasks as typing and using the mouse. In order to demonstrate that this is true the effects of motion on EEG control must be understood and compensated.

<u>Augmented Cognition</u>
In this effort we will develop and implement automated on-line noise and artifact bio-signal processing. We will also develop adaptive combiner for mixed-mode control

signals, including manual control and bio-signal control. This will be implemented and tested in a task using combined EEG-BCI and mouse for input.

Demonstration of Subvocal, BCI, Augmentation, and Gesture-based Device and Environment Control

Once these capabilities have been verified in preliminary tests, this will then enable the control of a graphical simulation environment depicting a task relevant to NASA. At this point separate demonstrations for control using EEG, sub-vocal speech, and gestures will be performed. This work will use similar feature space and pattern recognizers to demonstrate that selection and navigation is possible. This leads to the comparison of EMG and EEG and how one affects the other.

Pattern Recognition and Reliability of Algorithms

We will work on the following areas to improve the recognition rate and responsiveness of our pattern recognition algorithms:

- Feature extraction - Our feature extraction code will be enhanced with the addition of time-frequency based transforms such as complex discrete wavelet transforms (DWT). We will also incorporate methods for mapping from non-stationary series into multiple stationary time-series. Specifically we will use overlapping windows where the data within a window can be assumed close to stationary. Our feature extraction will include routines to filter out redundant and meaningless data with the use of information metrics such as mutual information (Pham, 1999).
- Model creation - Currently our model creation uses mixtures of Gaussians within a Hidden Markov Model context. We now propose to modify and extend our models to include hybridization of the HMMs via the addition of neural-network based density estimators. The specific NN-based estimators that we will evaluate will include Dynamic Cell Structure (dynamic splines), and kernel based methods. We will also examine the inclusion of non-Gaussian densities (such as the Laplacian) to be able to better model the higher order moments of the data. A pure Gaussian density is uniquely identified by two low order terms: mean and variance. When the data is not distributed as a Gaussian higher order moments are required to accurately model the distribution.
- On-line adaptation - The biggest challenge we face is adapting to the changes in the sampled signals that take place when we change between users. We will investigate on-line tuning of our models to adapt to these changes as well as to adapt to electrode degradation and failures.
- Physics and biology based pattern recognition systems – New pattern recognition methods such as spiking neurons and free energy minimization approaches (e.g. Bethe and Kikuchi approximations) may prove to be able to more efficiently find the proper parameterization of the required pattern recognition models then is currently possible. Understanding the inherent principals behind these systems is critical to improving the scaling and accuracies in pattern recognition.

4. Milestones

PCA 8 *Project*/Sub-Project Milestones	**Due Date**	**Metrics**
8.12 Demonstration of novel computational methods for neuro-electric machine control capabilities using EMG and EEG signals for closed-loop control, and human augmentation.	*Sep-06*	*Demonstrations of neuro-electric machine control capabilities including: a) using EMG to control a graphical simulation in a closed-loop simulation, b) using EEG for augmenting human cognitive performance, c) report of novel biological and physics inspired pattern recognition technology. Feasibility determinations of the strengths of bioelectric signals that can be used for device control and human performance augmentation for use in Aeronautics, space-based or commercial applications. Success metrics will be the ability of the technology to operate in near-real time with complex monitoring or control tasks. Performance tests of the new pattern recognition algorithms.*
8.12.1 Determination of EMG patterns associated with sub-vocal patterns, EEG patterns associated with cognitive function, and computational performance of new biological and physics inspired pattern recognition algorithms.	Mar-05	A research report on the statistical analysis of patterns and recognition performance. Statistical and performance descriptions.
8.12.2 Preliminary demonstration of novel computational methods for neuro-electric machine control capabilities using EMG and EEG signals for closed-loop control, and human augmentation.	Sep-06	First demonstration of EMG/EEG neuro-electric machine control capabilities. First performance tests of the new pattern recognition algorithms.

Task-Level Milestones:

Milestone	Description	Output Metric	Outcome
9.5 ICD: (NeMC) Silent Speech Recognition - Level I - 4QFY07 - RTOP 704-01-30	Perform speech recognition by sensing EMG and EEG signals.	Creating software to interpret these signals as speech.	Validate that the software can function without the participant actually speaking out loud.(L)
Analyze EMG -Level IV -2QFY02	Analyze sub-vocal EMG patterns of up to eight different words	Statistical analysis of signals.	Statistical description
Analyze EEG μ-rhythm -Level IV -2QFY02	Analyze EEG μ-rhythm from temporal lobe sources associated with classified sub-vocal patterns	Statistical analysis of signals.	Statistical description.
Test Sensors -Level IV -3QFY02	Test non-contact capacitive sensors provided to NASA for bio-electric recording.	Comparison of signal characteristics to wet electrodes	Validate that capacitive electrodes are adequate
Demo Sensors -Level III -4QFY02	Demonstrate bio-electric readout from capacitive sensors.	Measurement of signals from sensors.	Demonstration of continued use of sensors.
Develop pattern recog. s/w -Level IV -Q3FY03	Develop pattern recognition algorithms for EMG based sub-vocal speech	Creating software to interpret these EMG signals as speech.	Validation of initial algorithms.
Demo EMG sub-vocal control -Level III -Q4FY03	Demonstrate sub-vocal EMG pattern recognition for use in control of a graphical simulation.	Demonstration of controlling a simulation with unspoken commands.	Demonstration
Demo DDF 2-D mu-rhythm control -Level III -Q4FY03	Demonstrate 2-d control of a computer simulation using mu-waves (EEG)	Demonstration of control.	Demonstration
Develop Adaptive Training algorithms -Level IV -2QFY04	Design and implementation of adaptive software	Algorithms that can adapt over time	Algorithm implementation.
Extend vocabulary -Level IV -2QFY04	Extend the sub-vocal vocabulary (scale algorithms) to at least 20 words.	Algorithms can simultaneous handle 20 different unspoken words.	Algorithm validation.
Demo combined EEG control & state assessment -Level III -4QFY04	Pattern recognition of EEG for 2-D control and cognitive state assessment in a data driven task/environment.	Demo of control using EEG and cognitive state assessment.	Demonstration
Modify to use capacitive sensors -Level IV -4QFY04	Modify pattern recognition software to use the non-contact capacitive sensors	Recognition of signals from capacitive sensors	Recognition of patterns.
EMG sub-vocal speech control, gesture control, and EEG control/assessment in presence of motion -Level II Q2FY05 **PCA8.12.1**	Classifying EMG based sub-vocal speech and gestures for control & EEG control/state detection while subject is moving (such as using mouse or keyboard)	EMG control & EEG based control/state assessment of a computer simulation while moving	Report on statistical analysis of multi-modal control capabilities.
Real-time demo -Level I -3QFY06 **PCA 8.12**	Performing EMG based sub-vocal control and EEG control/assessment for real-time tasks.	Real-time pattern recognition.	Demonstration

Impact on NASA by completion of final milestone:

The demonstration of a dual modality EMG and EEG system which incorporates the capability for silent communication has the potential to provide Code R (Aerospace enterprise) with the following capabilities:

1. Speech recognition in extremely noisy environments such as the space station.
2. Computer command while restricted by a space suit.
3. Natural robotic and exoskeleton control.
4. Mobile control capability of remotely piloted/driven vehicles/planes.
5. Wearable computer input interface for mobile computing tasks such as maintenance and inventory control.

This milestone also will help other government agencies (in particular DoD) by providing the following capabilities:

1. Silent communication between soldiers
2. Hands free control of remote surveillance vehicles

5. Schedule

As listed in the task level milestone table.

6. Resources / Budget

Labor:

2.95	FTE
4.50	WYE

Procurement (excluding labor):

$0.389M Procurement

7. Management Approach

Deliverables (FY 2004):

- Research Technical Paper compliant with Ames Publication procedures (ARC 310 and ARC 1676), or equivalent procedural compliance for tasks located at NASA Glenn Research Center.
- Simulation / demonstration of technologies.
- Physical / experimental data acquisition and/or technology validation.

Environment / Equipment:

- All research will take place in the NeuroEngineering Laboratory Rm. 281 / Bldg. 269, Flight simulation facilities (CVSRF in Bldg. 257 or the VMS in Bldg. 243), and Flight test assets (AFDD OH-58C and DFRC F-15 Tail No. 837).

Compliance with Standards and Codes:

- 53.ARC.0009.2.1 Publication of research
- 53.ARC.0009.2 Management and performance of research

Applicable Quality System Procedures and Work Instructions:

- 53.ARC.0004.1
- 53.ARC.004.2

Process Monitoring Methods/Procedures:

- Performed to satisfy all Level I business requirements, described below:

Type	Frequency	Purpose	Reporting By	Content/Format	Comments
Technical Highlights	Weekly	Status updates and/or highlights	L4 Task Leads and Technical POCs	Informal text of monthly progress - indicate "None" for negative replies *e-mail text; web-site entry*	Unless significant progress is reported, can be brief
Quarterly Progress	Quarterly	Program Management Council (PMC)	L2 Managers	Text (and accompanying graphic, if any) of quarterly progress towards L1/L2 milestones *e-mail text; electronic copy of graphic; web site entry (under development)*	Progress towards all active L2/L3 milestones should be reported
Technical	Quarterly	Program	L2 Managers	One page text (Bullets: Objective,	Technical

Highlights		advocacy and reviews		Background, Accomplishment, Future Plans) and one page graphic *e-mail text; electronic copy of graphic; web site entry (under development)*	Highlights are used to promote the CICT Program and represent significant accomplishments
Milestone Summaries	Milestone due dates or completion	Program advocacy and reviews	L2 Managers	Detail description of milestone accomplishments relative to goals and success metrics. Background material including graphics, technical reports, publications, etc. *e-mail text, electronic copies of graphics, hardcopies of reports*	
Budget and Workforce Tracking	Monthly (5th working day of each month)	Status reports to ITSRPO and CFO	Center POCs for resource management	Spreadsheets, graphs at the 5-digit level. Include variance explanation for +/- 10% variances *e-mail text; electronic copy of graphs; web site entry (under development)*	Planned vs. actual commitments obligations and accruals at 5-digit level. Planned vs. actual CS and SSC workforce.
ATAC Sub-committee Reviews	Annual	To review and provide advice on research efforts	L1, L2, and L3 Managers and Technical POC's	Program, project, and sub-project plan on-site review on status, approach, and technical accomplishments	
LCPMC	Annual	To review status, budget, and milestones	L1 and L2 Managers	Program and Project tracking of budget and milestones	

8.0 Agreements

Space Act Agreements:
QUASAR Corporation (non-contact sensor development)

Internships:
Foothill/DeAnza (Student Interns)
Educational Associates Program (Student Interns)
National Research Council (Postdocs)

Grants:
UC Santa Cruz

SBIR:
QUASAR Corp. (EEG specific high density array development)